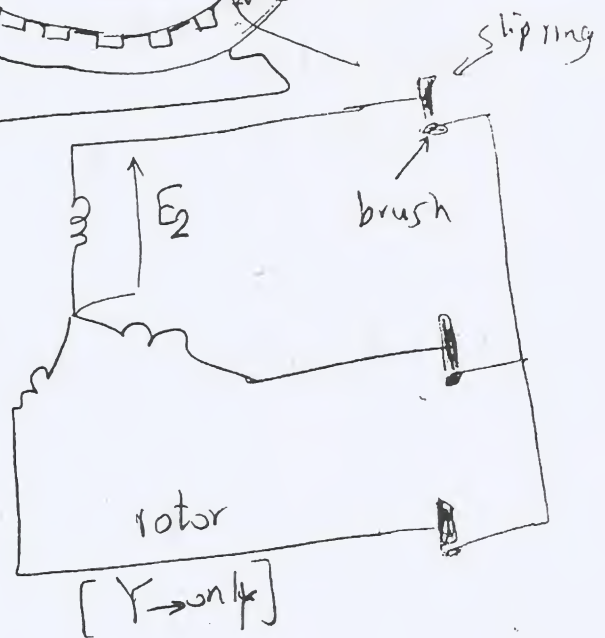
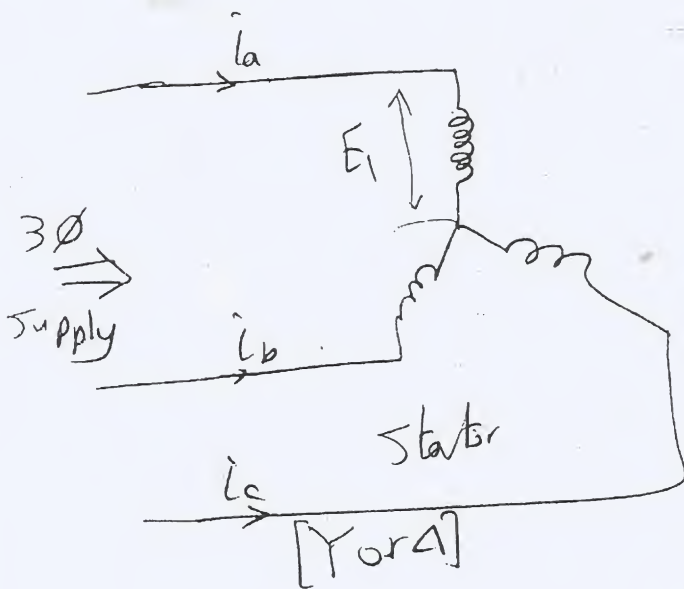
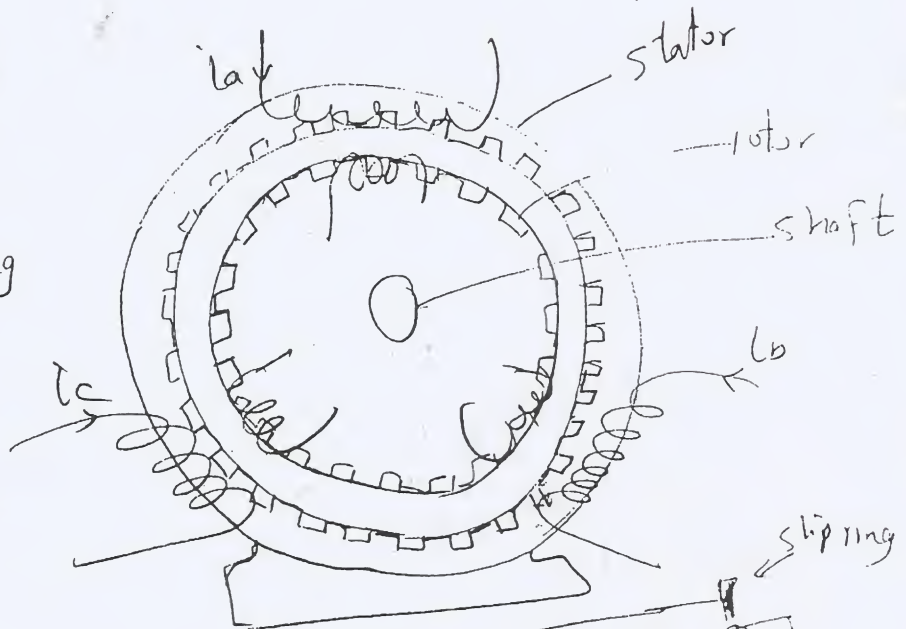
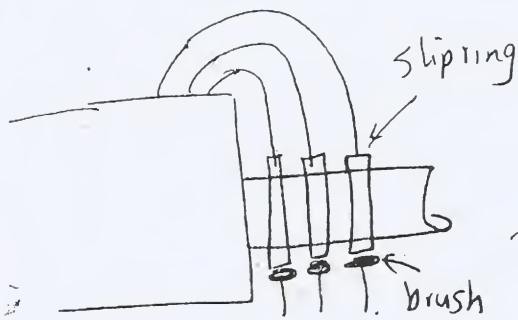


Three-phase Induction motor

2
Done

- Two types of I.M
- 1] wound rotor [slipping] type
 - 2] Squirrel cage rotor type

Slipping I.M



Rotating Flux $\xrightarrow[\text{by}]{\text{rotate}} n_s$

$n_s = \text{Synchronous speed} = \frac{60f_1}{P} \text{ (rpm)}$

$n = \text{motor [shaft] speed (rpm)}$

$2p =$ number of poles

$f_1 =$ Supply frequency (Hz)

$f_2 =$ rotor frequency (Hz)

$$\gamma_{lip} = S = \frac{n_s - n}{n_s} < 1 \Rightarrow n = (1 - S)n_s$$

$$\omega = 2 \frac{\pi n}{60} \text{ rad/sec}$$

$$\omega_s = \frac{2\pi n_s}{60}$$

$$\text{rad/sec}$$

$$w = (1-s)w_s$$

$$F_2 = 5 F_1$$

$$E_1 = \text{stator induced emf} = 4.44 f_1 \phi T_1 \text{ Kw}$$

$E_1 = \text{stator induced emf} = 4.44 f_1 \phi T_1 \text{ Kw}$
 $E_2 = \text{rotor induced emf} = 4.44 f_2 \phi T_2 \text{ Kw}$
 $E_2 = 4.44 s f_1 \phi T_2 \text{ Kw}$

$T =$ number of turn
 $K_w =$ winding factor

At stand still [rotor blocked] $\Rightarrow S = 1$

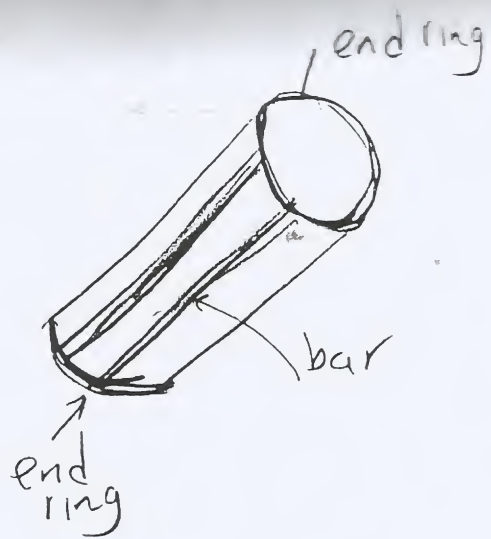
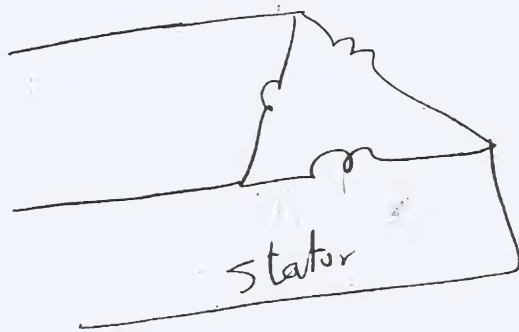
$$E_{20} = \text{rotor emf at stand still.}$$

$$= 4.44 \underline{F_1} \phi T_2 \text{ Kw}$$

$$E_2 = 5 E_{20}$$

$$a = \frac{T_1 K_{w1}}{T_2 K_{w2}}$$

☞ Squirrel Cage IM

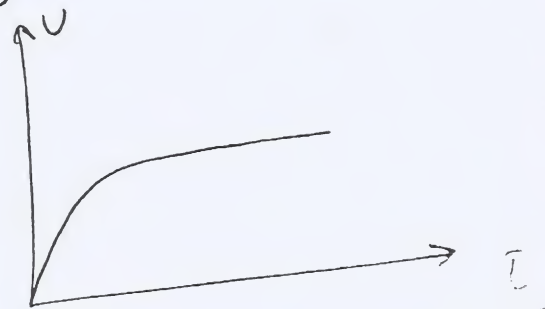


- Same function of slip ring IM.
- but no external rotor terminal
- used in small rating Application

☞ Why must use Carbon brush in slip ring IM?

Carbon resistance represent non linear resistance as shown relation between voltage & current for brush resistance

⇒ constant voltage drop with increasing current



☞ Why rotor must constructed as a circle?

Circle give large Area with small Circumference, so saving in material and saving in copper ⇒ less copper losses ⇒ more efficiency

Starting of 3-phase I.M

$$I_2' = \frac{V_1}{\sqrt{(r_1 + r_2/s)^2 + (x_1 + x_2)^2}}$$

at starting $s=1$

$$\begin{array}{l} I_{st} \propto V \\ T_{st} \propto V^2 \end{array}$$

$$I_{st}' = \frac{V_1}{\sqrt{(r_1 + r_2)^2 + (x_1 + x_2)^2}} = \text{Very large current}$$

So it must be reduce starting current
by

- 1] using external rotor resistance [slip ring type]
- 2] reduce input stator voltage [slip ring & squirrel cage]

Starting of Squirrel cage motor

1] direct switching

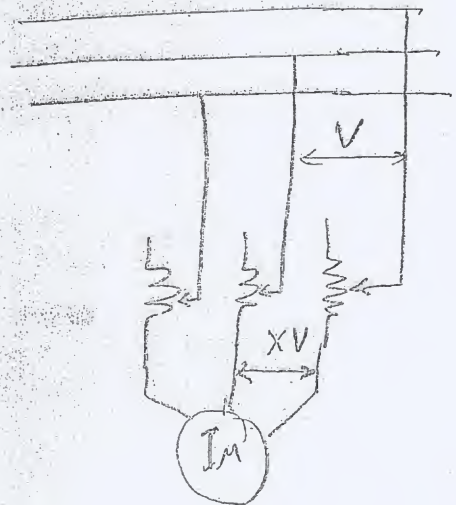
For small motor less than 10 hp connected to infinite bus bar

2] Reduced input voltage

a] using series resistance

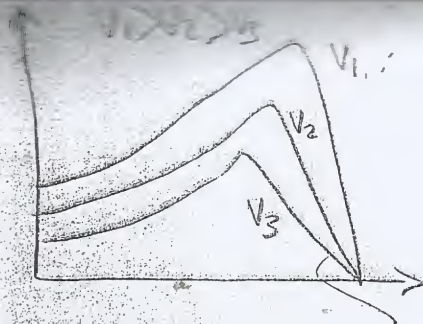
$$\frac{I_{st} \propto V}{I_{st} \propto V} = X$$

$$\frac{T_{st} \propto V}{T_{st} \propto V} = X^2$$



advantage

- reduce starting current
- improve P.f at starting
- simple method



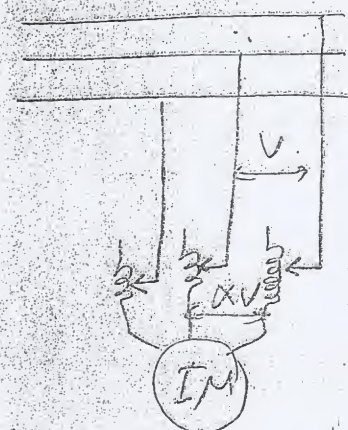
disadvantage

- reduce starting torque
- less efficiency method

b) Using Series Reactor

advantage

- reduce starting current
- no copper loss
- high efficiency



disadvantage

- reduce starting torque
- low P.f

c) Auto transformer

$$\frac{I_{st} \times V}{I_{st} V} = X = \frac{V_2}{V_1}$$

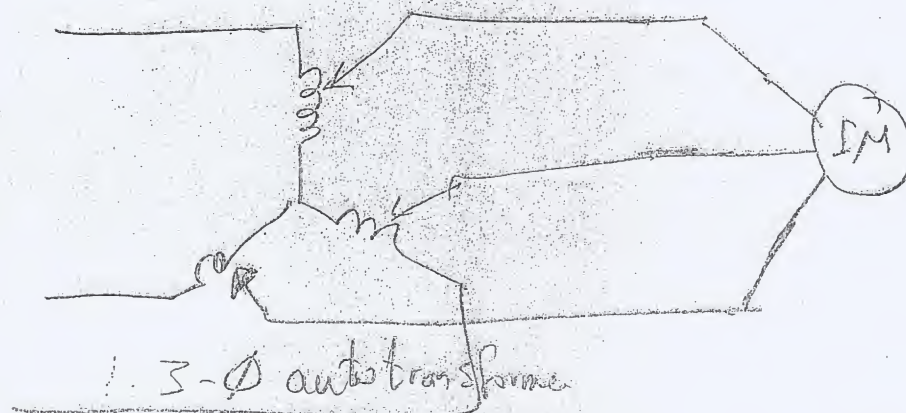
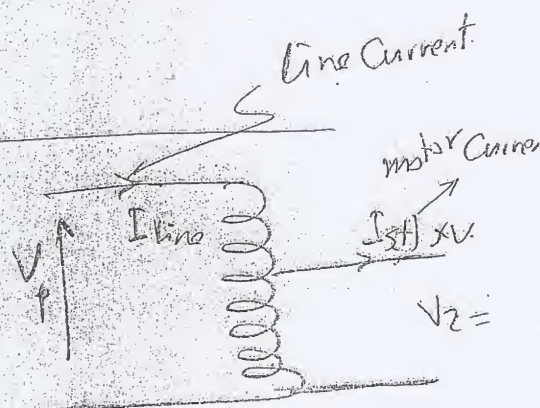
$$\frac{I_{line}}{I_{st} \times V} = \frac{V_2}{V_1} = X$$

$$I_{line} = X I_{st} \times V$$

$$I_{line} = X^2 I_{st} V$$

$$\frac{T_{st} \times V}{T_{st} V} = X^2$$

single-phase



1. 3-φ auto transformer

VS

advantage

- reduce starting current
- no voltage drop across auto transformer
- high efficiency
- saving size [one wdg per phase]
- reduce line current at starting

disadvantage

- reduce starting torque
- more expensive method

d] Y/Δ switch

At starting connect Y

At running connect Δ

$$\frac{I_{st} \Delta_{xv}}{I_{st} \Delta v} = \frac{1}{\sqrt{3}} = X$$

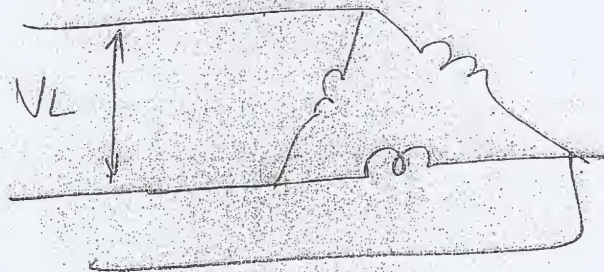
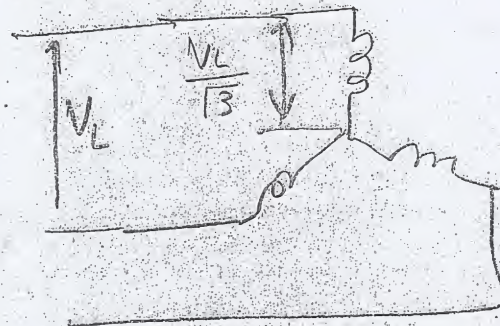
$$\frac{T_{st} \Delta_{xv}}{T_{st} \Delta v} = \frac{1}{3} = X^2$$

advantage

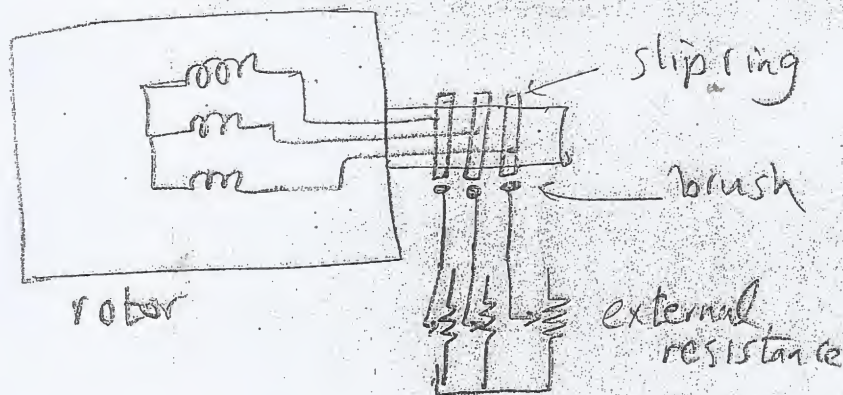
- reduce starting current
- simple & cheap method
- no losses \Rightarrow high efficiency

disadvantage

- reduce starting torque
- $X = 1/\sqrt{3} \Rightarrow$ constant

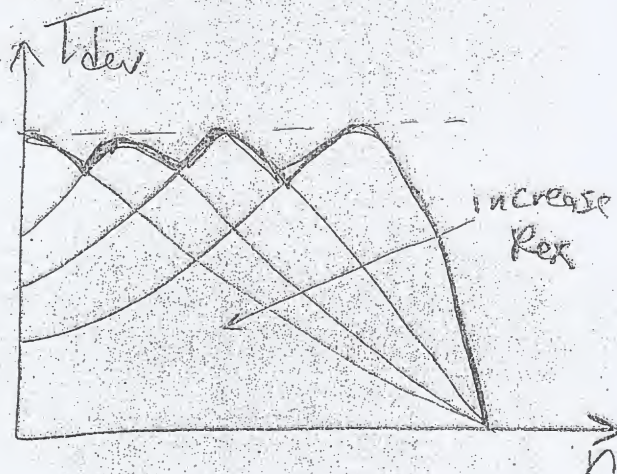


Starting of wound rotor [slip ring] I/M



- At starting, total external resistance connected to rotor circuit
- After starting Period, external resistance cut out in steps

$$I_{2st} = \frac{V_1}{\sqrt{(r_1 + r_2 + R_{ex})^2 + (X_1 + X_2)^2}}$$



to achieve max torque at starting

$$T_{max} = T_{st}$$

$$\boxed{S_{int} = 1}$$

$$\Rightarrow \frac{r_2 + R_{ex}}{\sqrt{r_1^2 + (X_1 + X_2)^2}} = 1$$

Advantage

- reduce starting current
- increase starting torque
- improve P-f

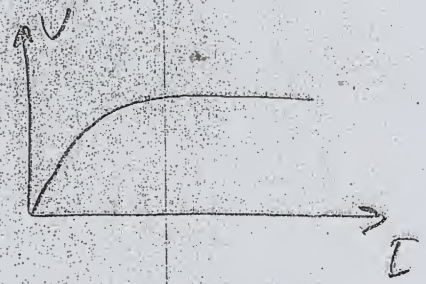
disadvantage

- large copper loss
- less efficiency

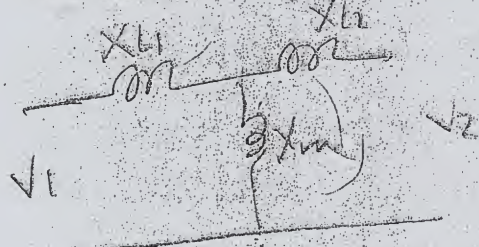
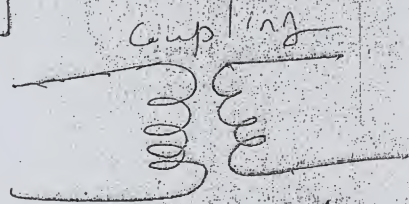
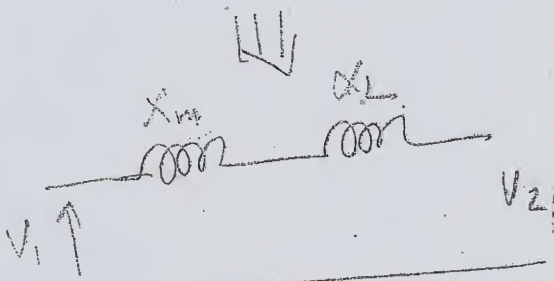
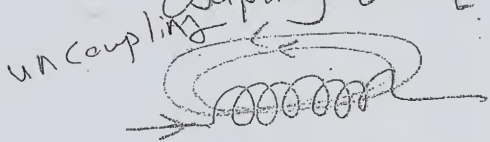
✓

Q Why we use Carbon brush?

Carbon resistance non linear where its voltage-current relation as shown so it has constant V-D at high current



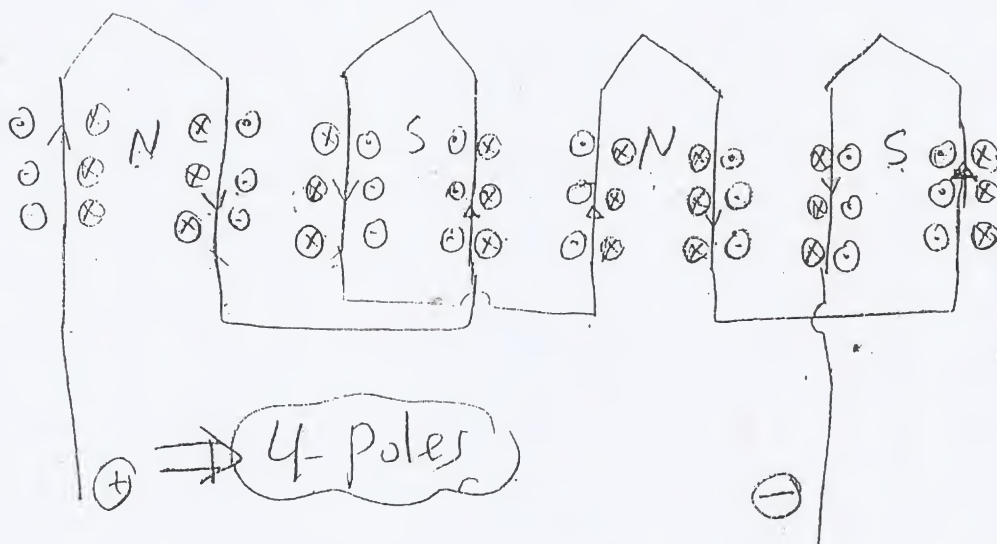
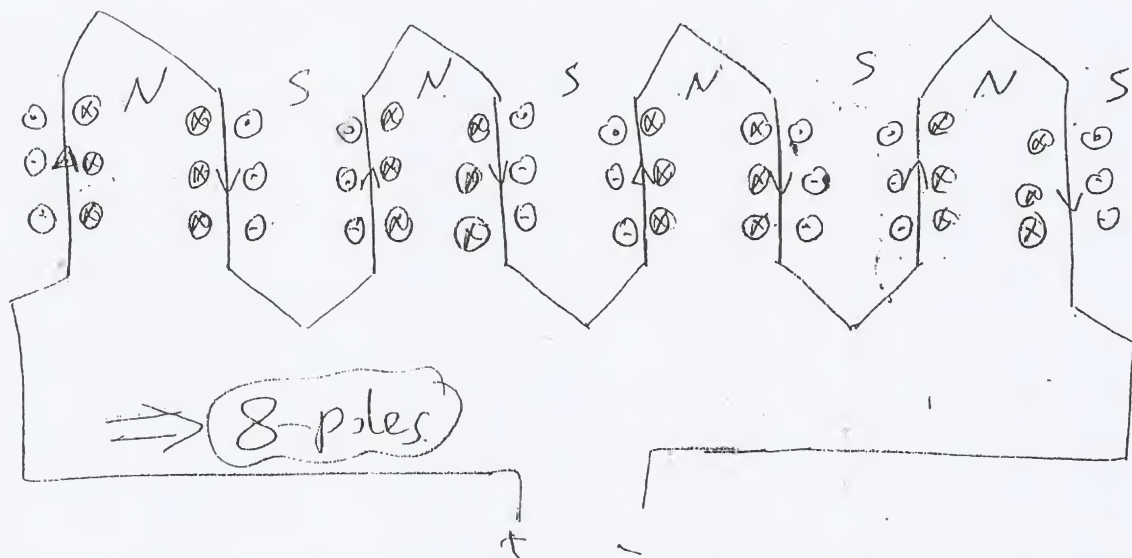
Q What's the difference between uncoupling coil & coupling coil [transformer]



Small voltage drop in X_{L1} & X_{L2}

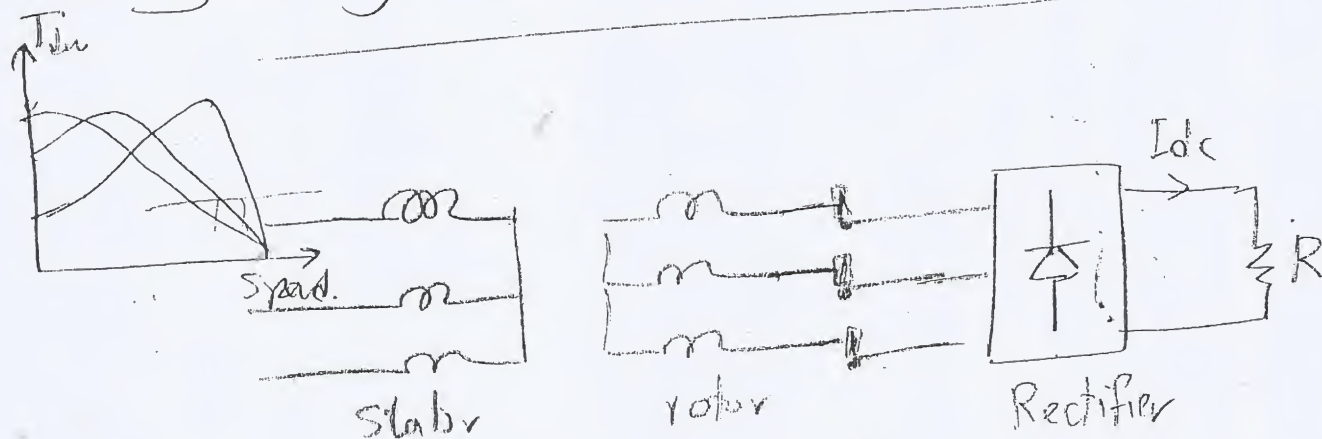
X_m = magnetizing reactance
 X_L = leakage reactance
 large voltage drop in X_m , X_L

4) Change number of poles

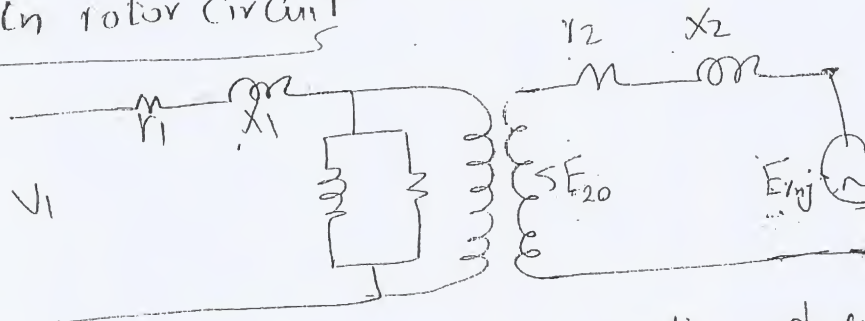


B) Slip ring Induction motor

by using external Rotor resistance



2) Injection voltage in rotor circuit



- When injection voltage is in phase opposition to the induced rotor emf it amounts to increasing rotor resistance.
[Subsynchronous]
- When injection voltage is in phase with induced rotor emf it is equivalent to decreasing rotor resistance.
[Supersynchronous]

Induction generator (I-G)

- IM Can be used as a generator but it need source of reactive power as a capacitor or it can consume reactive power from the network.

- due to its simplicity it widely used in wind turbine application.

المبادل (المبادل) [commutator]

Braking

1] mechanical braking

2] Regenerative braking

the kinetic energy stored on the rotor mass may be returned to supply after converting it from DC to AC by inverter circuit

3] plugging

4] Single phasing

- connect IM as a single phase machine with single phase supply
- produce pulsating flux, so IM will not rotate



Using double layer winding

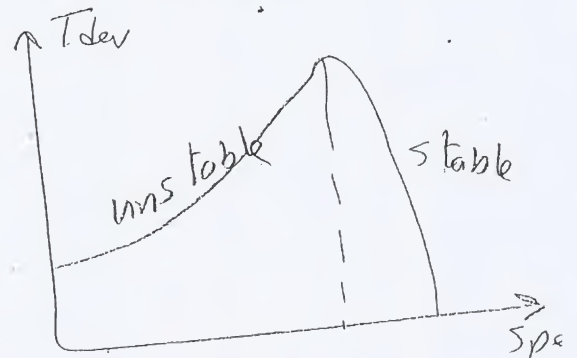
by using double layer windings, pitching of coil is possible \Rightarrow advantage of chording



☑ Squirrel cage I.M is considered constant speed machine

$$S = \frac{n_s - n}{n_s} = 5\% \rightarrow 20\%$$

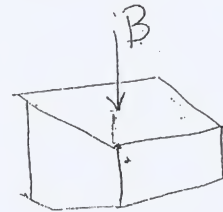
\rightarrow usually in normal I.M the slip range from 5% to 20% so that the motor speed changes very little from no load to full load condition



Short notes about eddy current loss & hysteresis loss

- * For any conducting material. When external Flux linked with the conducting material, eddy current will be circulated inside the material producing magnetic flux in reverse direction with external flux so total flux will be reduced.

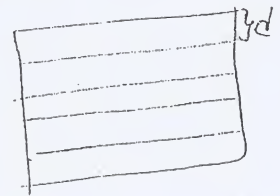
$$P_e = K_e F^2 B^2$$



- To reduce eddy current losses, use silicon steel lamination
 \Rightarrow high resistance \Rightarrow low current flow in the material.

$$P_e \propto d^2$$

d = thickness

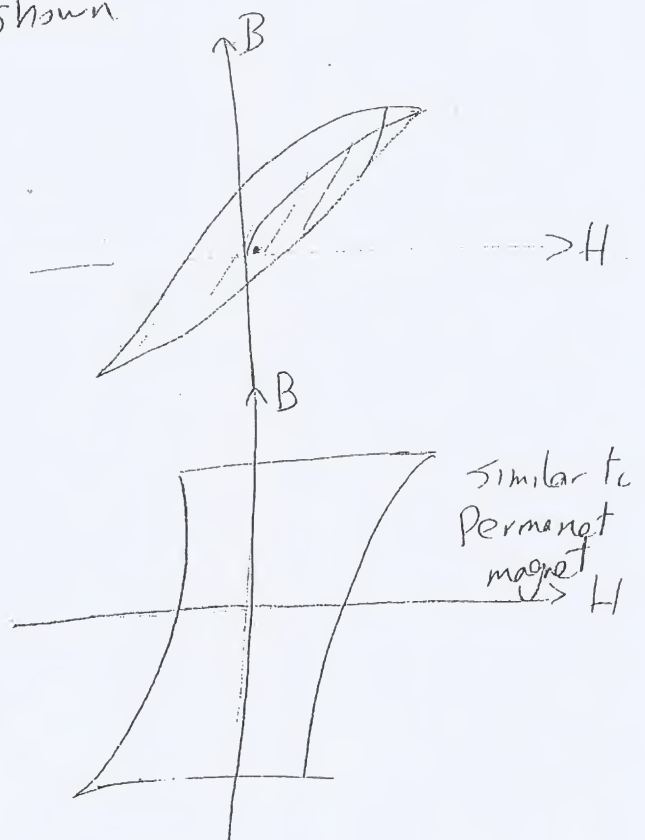


- * For magnetic material the relation between flux density (B) and Field intensity (H) as shown.

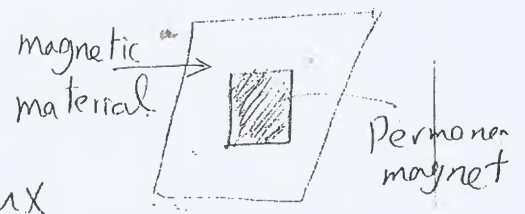
- \Rightarrow there is a residual flux
- \Rightarrow by increasing Area of the loop the hysteresis loss increased

$$P_h = K_h F B^x$$

$x = 1.5 \rightarrow 2.5$
 taken $x \approx 2$



Why permanent magnets stored by putting them on magnetic surface?



- To provide a path of the magnetic flux lines so that the magnetic flux from domain will be in the same direction.
- If magnet put in the air it loses its magnetic flux line in the air.

Disadvantages of using Aluminum in squirrel cage IM

Aluminum usually contains impurities due to that some bars in squirrel cage have a high resistance \Rightarrow low current path in these bars, so that the force not equal for all bars producing vibration.

2) Distribution Factor

$$\theta + \alpha_s = \theta + 2$$

$$(\alpha_s = 2)$$

$$\Delta[0ab]$$

$$\sin\left(\frac{9\alpha_s}{2}\right) = \frac{ab}{R}$$

$$E_r = 2ab$$

$$= 2 * R \sin\left(\frac{9\alpha_s}{2}\right)$$

from $\Delta[0xy]$

$$\sin\left(\frac{\alpha_s}{2}\right) = \frac{E_c/2}{R}$$

$$\Rightarrow R = \frac{E_c}{2 \sin(\alpha_s/2)}$$

$$E_r = 2 * E_c * \frac{\sin(9\alpha_s/2)}{2 \sin(\alpha_s/2)} = E_c \frac{\sin(9\alpha_s/2)}{\sin \alpha_s/2}$$

$$K_d = \frac{\text{vectorial sum}}{\text{algebraic sum}} = \frac{E_r}{2 E_c} = \frac{\sin(9\alpha_s/2)}{2 \sin(\alpha_s/2)}$$

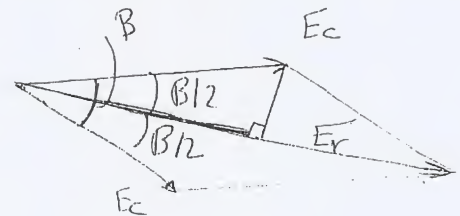
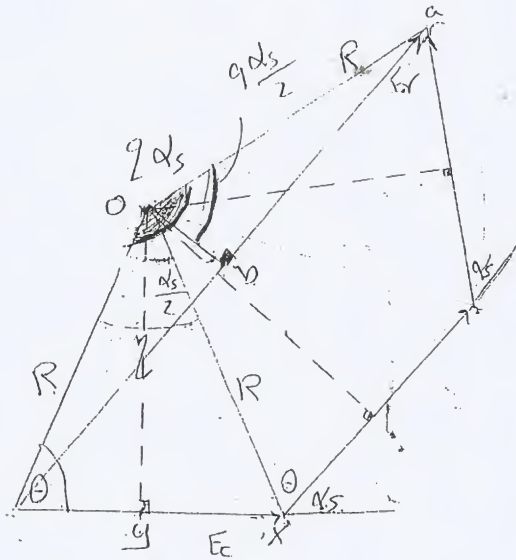
$$\left(K_d = \frac{\sin(9\alpha_s/2)}{2 \sin(\alpha_s/2)} \right) \quad \text{D.D.}$$

Chording Factor

$$\frac{E_r}{2} = E_c \cos B/2$$

$$E_r = 2 E_c \cos B/2$$

$$K_p = \frac{E_r}{2 E_c} = (\cos B/2)$$



$$S_{mt} = \frac{r_2}{\sqrt{r_1^2 + (x_1 + x_2)^2}}$$

$$T_{dev} = \frac{3V_1^2 r_2 / s}{W_s \left[\left(r_1 + \frac{r_2}{s} \right)^2 + (x_1 + x_2)^2 \right]} = \frac{K/s}{\left(r_1 + \frac{r_2}{s} \right)^2 + (x_1 + x_2)^2}$$

$$T_{max} \quad \text{when} \quad \frac{dT_{dev}}{ds} = 0$$

$$-\frac{K}{s^2} \left[\left(r_1 + \frac{r_2}{s} \right)^2 + (x_1 + x_2)^2 \right] - 2 \left(r_1 + \frac{r_2}{s} \right) \times \left[\frac{-r_2}{s^2} \right] \times \frac{K}{s} = 0$$

$$- \left[r_1^2 + 2r_1 \frac{r_2}{s} + \left(\frac{r_2}{s} \right)^2 \right] + (x_1 + x_2)^2 + 2r_1 \frac{r_2}{s} + 2 \left(\frac{r_2}{s} \right)^2 = 0$$

$$- r_1^2 + \left(\frac{r_2}{s} \right)^2 - (x_1 + x_2)^2 = 0$$

$$\left(\frac{r_2}{s} \right)^2 = r_1^2 + (x_1 + x_2)^2$$

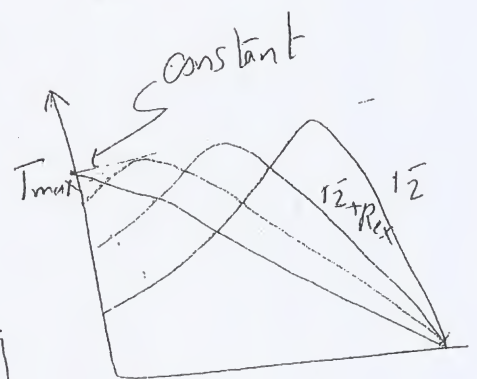
$$\Rightarrow \frac{r_2}{s} = \sqrt{r_1^2 + (x_1 + x_2)^2}$$

$$S = \frac{r_2}{\sqrt{r_1^2 + (x_1 + x_2)^2}} = S_{mt} = \text{Slip at Max torque}$$

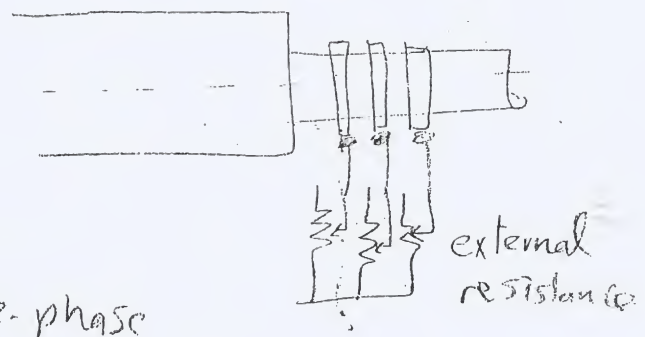
$$T_{max} = \frac{3V_1^2 r_2 / S_{mt}}{W_s \left[\left(r_1 + \frac{r_2}{S_{mt}} \right)^2 + (x_1 + x_2)^2 \right]}$$

$$\Rightarrow T_{max} = \frac{3V_1^2}{2W_s \left[r_1 + \sqrt{r_1^2 + (x_1 + x_2)^2} \right]}$$

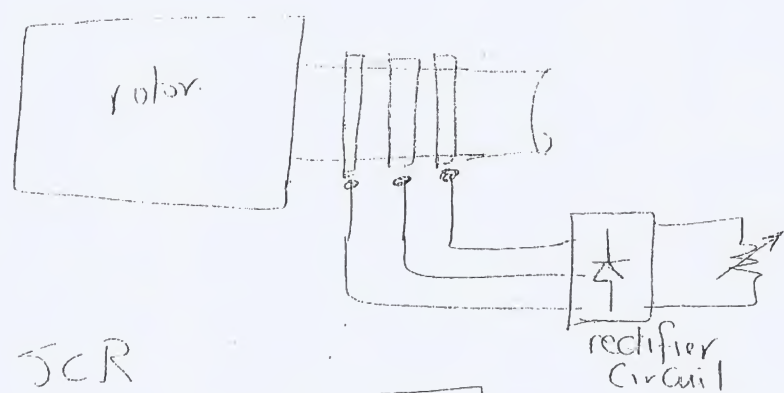
T_{max} not depend on r_2



starting of slip ring IM using external rotor resistance

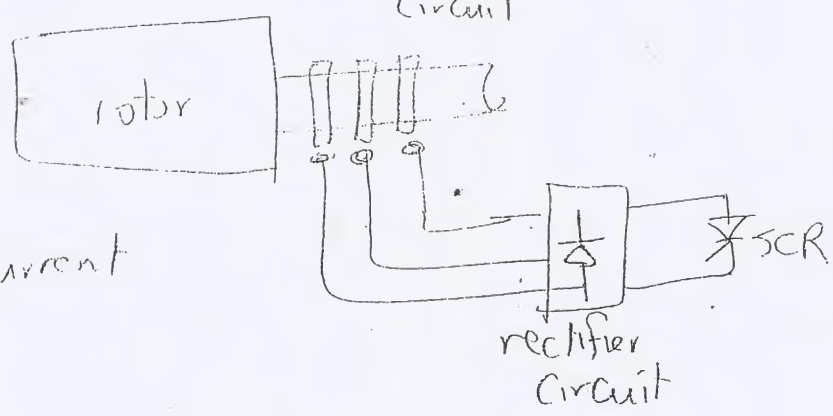


large copper losses in Three-phase resistance. So we can improve it by using one resistance and rectifier circuit.



OR using SCR

by changing firing angle of SCR the value of starting current can be reduced

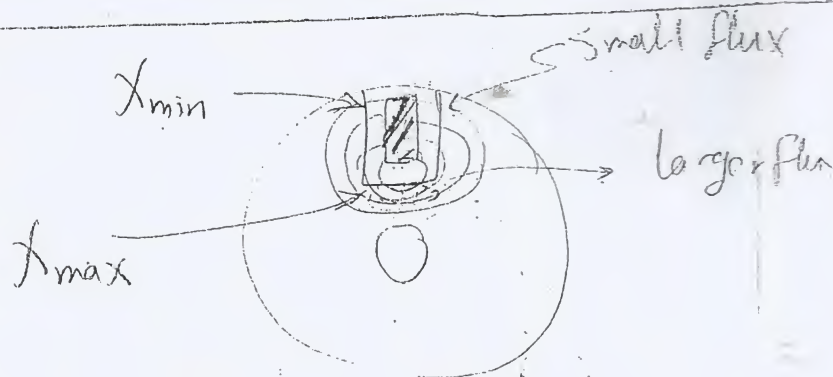


Effect of Flux on reactance value for Deep bar

motor
 $L \propto \phi$

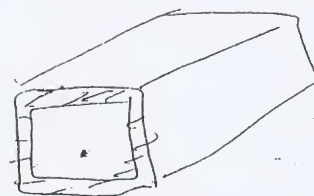
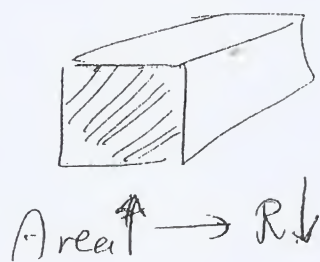
$$L = \frac{N\phi}{I}$$

$$X = 2\pi f \cdot L$$



Effect of skin effect of starting resistance

- At starting $f_2 = S f_1 \Rightarrow (f_2 = f_1) \Rightarrow$ high rotor frequency so that rotor resistance is high - producing high starting torque. [due to skin effect current pass in the surface]
- when motor speed increase so that f_2 decrease producing low rotor resistance.



Area ↓ ⇒ R ↑

$$f_2 = f_1$$

double Cage I.M

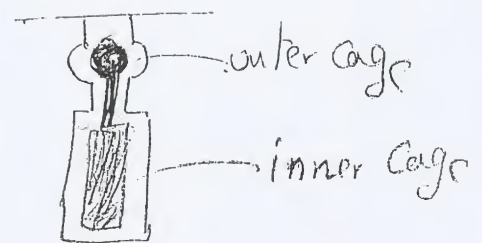
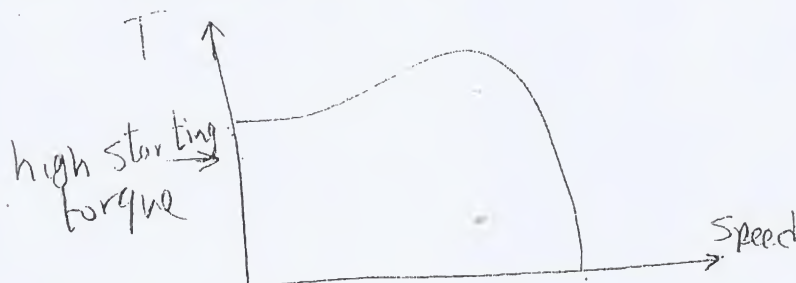
- The main disadvantage of Squirrel-Cage I.M, is

its poor starting torque due to low rotor resistance, so must increase rotor resistance but it give low mot efficiency

- to achieve high starting torque with high running efficiency we will use double cage motor

- outer cage has high resistance and low reactance to resistance ratio

- Inner cage has low resistance and high reactance to resistance ratio



- At starting, rotor frequency (f_r) is high, so reactance of inner cage is high, so that most of starting current pass in outer cage producing high starting torque [skin effect]

- As speed increase, the rotor frequency decrease, so reactance and impedance of the inner cage decrease and become very small under normal operation, most of motor current pass in the inner cage producing low resistance & high efficiency

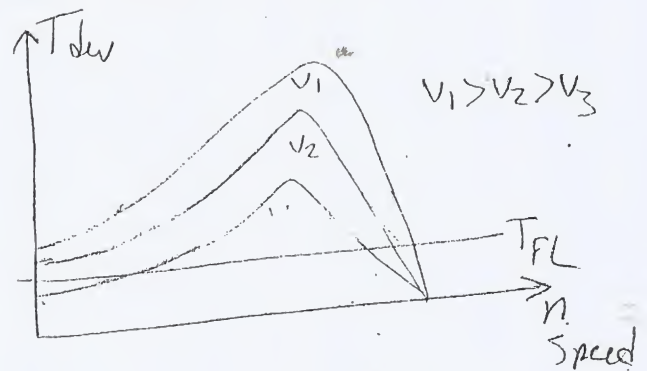
Speed control of 3-phase Induction motor

1) Squirrel Cage IM

1) Voltage control

used for range
(10% → 15%) of
rated speed

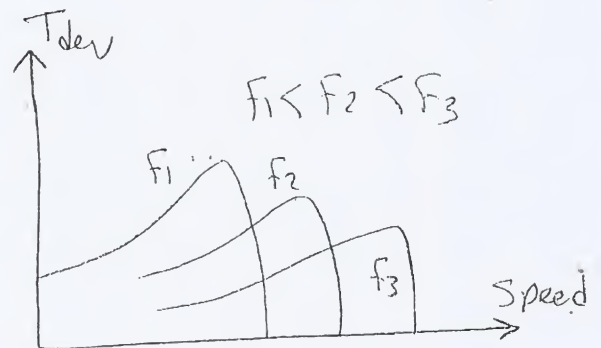
⇒ low starting torque [$T_s < T_{FL}$] ⇒ motor will not rotate



2) Frequency control

$$E = 4.44 f_i \phi N_{kw} = V$$

$$n_s = \frac{60f}{p}$$



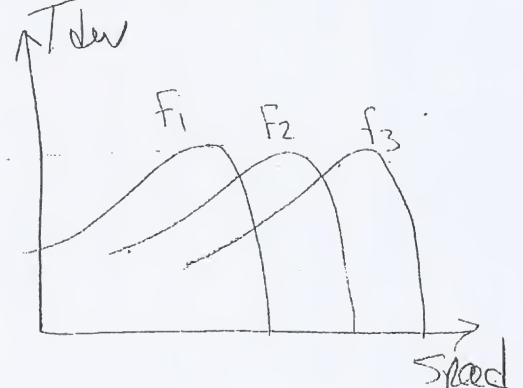
→ by reducing frequency, the flux ϕ increased until saturation. [Large current drawn from the supply].
So must use $\frac{V}{f} = \text{constant}$ to produce constant flux (ϕ)

→ by increasing frequency max torque & starting torque will be reduced. [also $x \uparrow \Rightarrow V \cdot D \uparrow$]

3) Voltage frequency control (V/f)

⇒ constant maximum torque

⇒ no saturation problem



III (3)

Total induced enf / phase in Synchronous machine = E

$$E = 4.44 f \Phi T K_w$$

f = Frequency Hz

Φ = Flux Wb

T = number of turns / phase

K_w = winding Factor = $K_p K_d$

K_p = Chording Factor

K_d = distribution Factor

$$K_p = \cos(B/2)$$

$$K_d = \frac{\sin(q \alpha_s / 2)}{q \sin(\alpha_s / 2)}$$

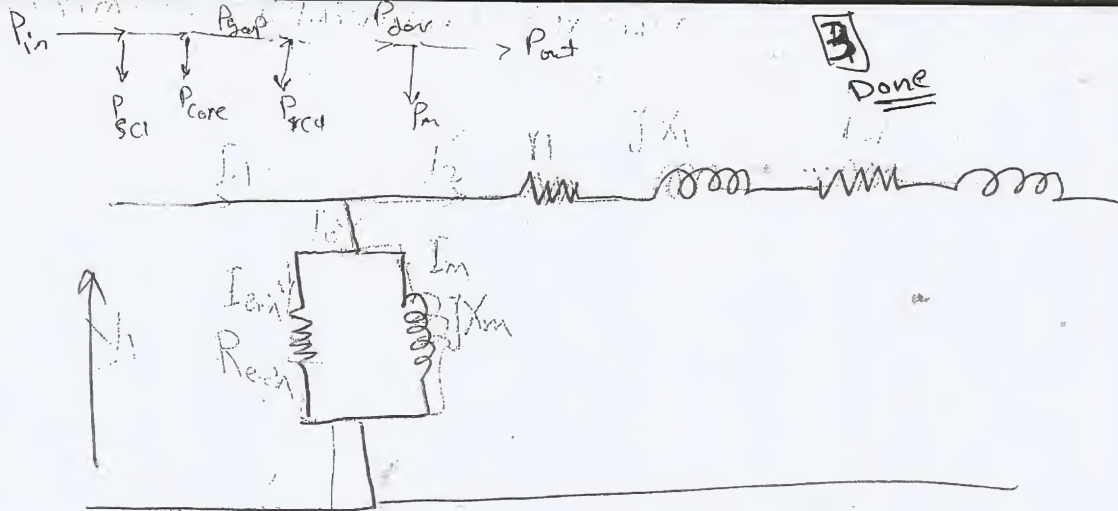
B = Chording angle

q = number of slot / pole / phase

α_s = slot angle

$$\alpha_s = \frac{180}{m \cdot q}$$

, m = number of phases



V_1 = Input voltage [stator]

I_1 = " Current [stator]

I_0 = No load Current

I_m = magnetizing Current

I_{erh} = eddy & hysteresis Current

I_2 = rotor Current

I_2' = rotor Current refer to stator

R_1 = stator resistance

X_1 = " reactance

R_2 = rotor resistance

X_2 = " reactance

R_2' = " resistance refer to stator = $a^2 R_2$

X_2' = " reactance " " " = $a^2 X_2$

$$I_0 = I_{erh} + I_m = V_1 \left[\frac{1}{R_{erh}} + j \frac{1}{X_m} \right] = |I_0| \angle -\phi_0$$

$$|I_0| = \sqrt{|I_{erh}|^2 + |I_m|^2}$$

$\cos \phi_0$ = no load Power Factor [Lag]

$$I_2' = \frac{V_1}{(r_1 + r_2/s) + j(x_1 + x_2)} = |I_2| \angle$$

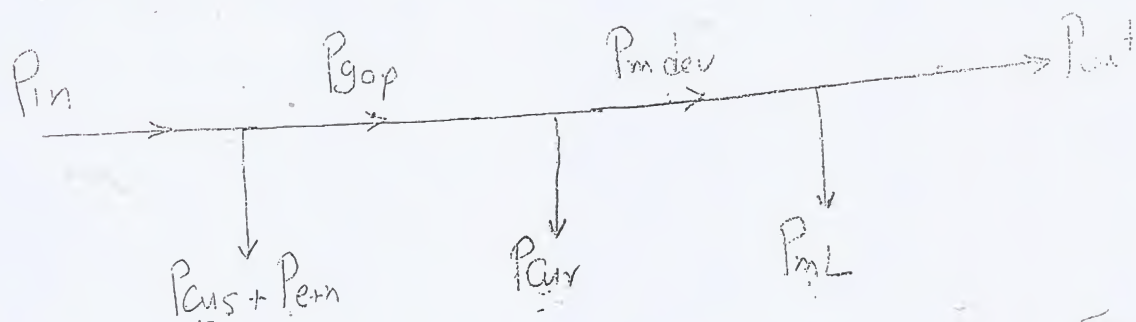
$$|I_2| = \frac{V_1}{\sqrt{(r_1 + r_2/s)^2 + (x_1 + x_2)^2}}$$

$$I_1 = I_2 + I_0 = I_1 \angle \theta_{I_1} \leftarrow \text{Lag } \phi$$

$$\text{Input Power Factor} = \cos(\theta_{V_1} - \theta_{I_1}) \rightarrow \text{Lag}$$

$$= \cos \phi$$

Power Flow diagram



$$P_{in} = \text{Input stator Power} = \sqrt{3} V_1 I_1 \cos \phi \quad [V_1, I_1 \text{ line}]$$

$$= 3 V_1 I_1 \cos \phi \quad [V_1, I_1 \text{ phase}]$$

$$P_{cys} = \text{stator Copper losses} = 3 I_1^2 r_1 \rightarrow \text{Exact}$$

$$= 3 I_2^2 r_1 \rightarrow \text{Approximate}$$

$$P_{eh} = \text{Iron Loss [eddy \& hysteresis]}$$

$$P_{gap} = \text{Air gap Power} \leftarrow$$

$$= \text{Power delivered from stator to rotor}$$

$$= \text{Input rotor Power}$$

$$P_{cur} =$$

$$P_{gap} = 3 I_2^2 r_2 / s$$

$$\rightarrow P_{cur} = s P_{gap}$$

P_{dev} = developed mechanical power

$$= (1-s) P_{gap}$$

P_{mL} = total mechanical losses

P_{out} = output [useful] power

$$\eta = \text{efficiency} = \frac{P_{out}}{P_{in}} \%$$

$$T_{dev} = \text{developed torque} = \frac{P_{dev}}{\omega} = \frac{(1-s) P_{gap}}{(1-s) \omega_s}$$

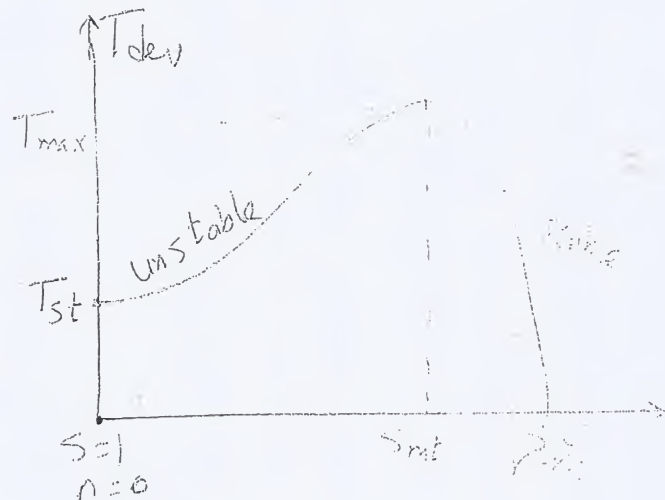
$$T_{dev} = \frac{P_{dev}}{\omega} = \frac{P_{gap}}{\omega_s} \quad (N \cdot m)$$

or $T_{dev} = P_{gap}$ [Synchronous watt]

$$T_{mL} = \text{mechanical loss torque} = \frac{P_{mL}}{\omega} \quad (N \cdot m)$$



$$T_{dev} = \frac{3 V_1^2 / s}{\omega_s [(r_1 + r_2/s)^2 + (X_1 + X_2)^2]}$$



At starting $(s=1)$

At max torque $s = s_{mt}$

$$s_{mt} = \frac{r_2}{\sqrt{r_1^2 + (X_1 + X_2)^2}}$$

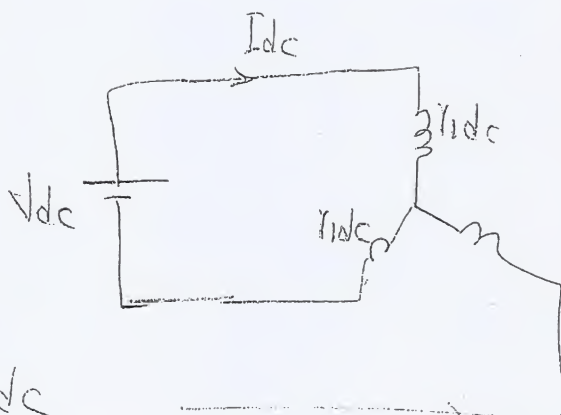
3 Determination the Parameter of the Equivalent Circuit

1 Dc test

$$V_{dc \text{ line}} = \frac{V_{dc}}{I_{dc}}$$

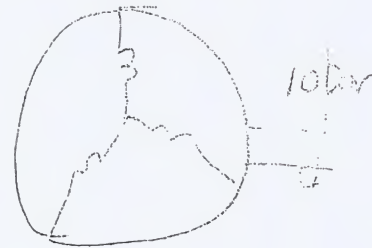
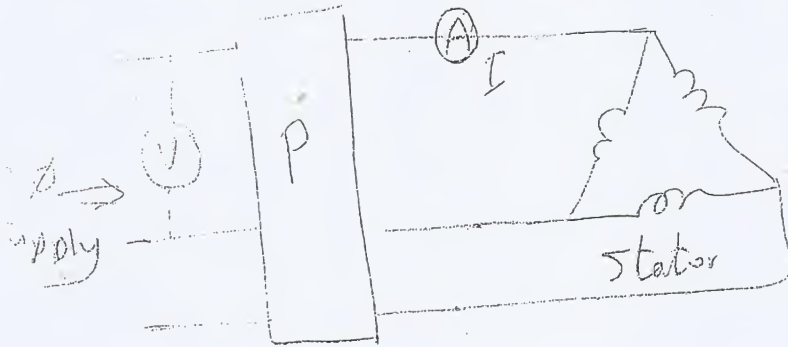
$$r_{dc} = \frac{1}{2} V_{dc \text{ line}}$$

$$r_{ac} = 5 \text{ km effect} \times r_{dc}$$



$$V_{dc} = \frac{3}{2} V_{deline}$$

$$V_{ac} = (\text{kin effect}) A V_{dc}$$



2) No load test
 $n \approx n_s \Rightarrow S = 0$

$I_0, V_0, P_0 \Rightarrow \text{phase}$

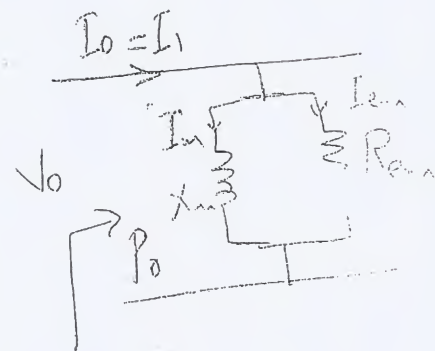
$$\cos \phi_0 = \frac{P_0}{V_0 I_0}$$

$$I_{erh} = I_0 \cos \phi_0 =$$

$$I_m = I_0 \sin \phi_0 =$$

$$R_{erh} = \frac{V_0}{I_{erh}}$$

$$X_m = \frac{V_0}{I_m}$$



Blocked Rotor test

$$I_0 \ll I_{sc}$$

$$R_{eq} = R_1 + R_2'$$

$$X_{eq} = X_1 + X_2'$$

$I_{sc}, V_{sc}, P_{sc} \Rightarrow$ phase

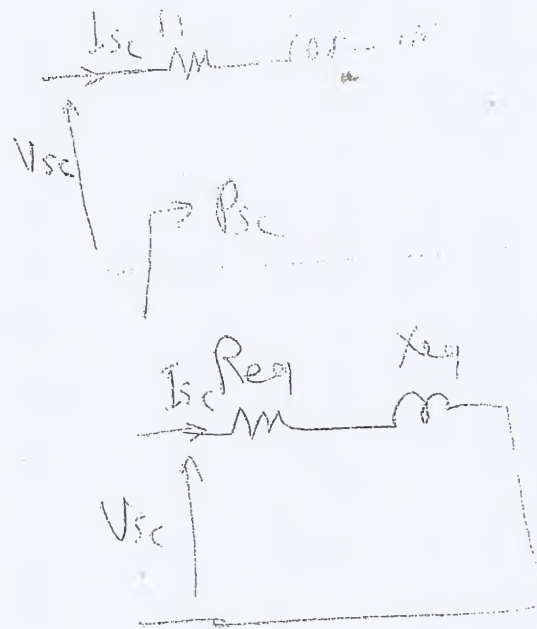
$$R_{eq} = \frac{P_{sc}}{I_{sc}^2}$$

$$Z_{eq} = \frac{V_{sc}}{I_{sc}}$$

$$X_{eq} = \sqrt{Z_{eq}^2 - R_{eq}^2}$$

Usually: $X_1 = X_2' = \frac{X_{eq}}{2}$

$R_2' = R_{eq} - R_1 \leftarrow$ dc test



⇒ To achieve max torque at starting

⇒ connect rotor resistance

$$\sin \theta = 1 = \frac{R_2 + R_{ext}}{\sqrt{R_1^2 + (X_1 + X_2)^2}}$$

$$P_e = K_e f^2 B_m^2$$

f - Frequency

B_m - max Flux

$$P_h = K_h f B_m^x$$

$$x = 1.5 \longrightarrow 2.5$$

take $x = 1.6$

$$= 4.44 f B_m A T$$

$$\Rightarrow (B_m \propto \frac{E}{f})$$

$$P_e = K_e' f^2 \left(\frac{E}{f}\right)^2 = K_e' E^2 \quad (P_e = K_e E^2)$$

$$P_h = K_h' f \left(\frac{E}{f}\right)^{1.6} = K_h' f^{-0.6} E^{1.6}$$

$$P_h = K_h' f^{-0.6} E^{1.6}$$

$$\frac{P_{e2}}{P_{e1}} = \left(\frac{E_2}{E_1}\right)^2$$

$$\frac{P_{h2}}{P_{h1}} = \left[\frac{f_1}{f_2}\right]^{0.6} \left(\frac{E_2}{E_1}\right)^{1.6}$$

Generated Electric Power as a Sine wave

For transformer $\phi = \phi_m \sin \omega t$

Farady law $e = -N \frac{d\phi}{dt}$

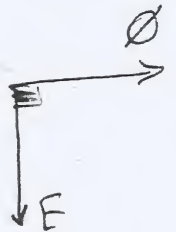
$$e = -N \omega \phi_m \cos \omega t$$

$$e = -\omega N \phi_m \sin(\omega t - \pi/2)$$

$$e = E_{max} \sin(\omega t - \pi/2)$$

$$E_{max} = 2 \pi f N \cdot \phi_m$$

$$E_{rms} = \frac{E_{max}}{\sqrt{2}} = \frac{2 \pi f \phi_m N}{\sqrt{2}} = 4.44 f \phi_m N$$



So Induced emf lag flux by $\pi/2$

* تفاعل الـ sine بين الـ sine و الـ sine
بين الـ sine و الـ sine

For induction machine

$$E = 4.44 f \phi N K_w$$

$$K_w = \text{winding factor} = K_p \cdot K_d < 1$$

$K_p =$ chording factor [pitch]

$K_d =$ distribution factor

Calculation of Distribution Factor

1) Single-phase machine

Assume

$$2p = 2$$

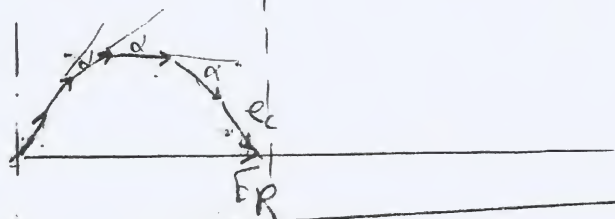
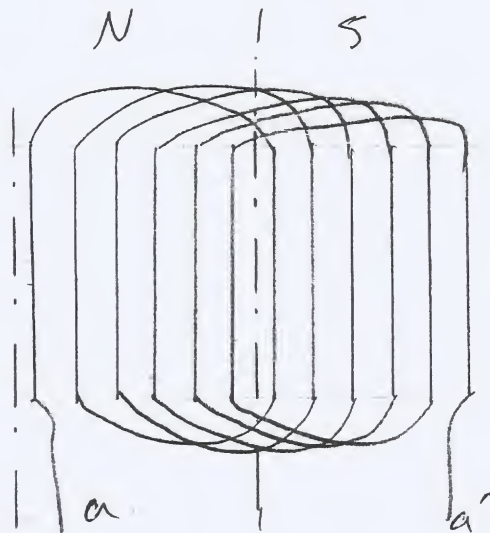
$$\text{Number of slot} = 12$$

$$K_d = \frac{\text{Vectorial sum of EMF}}{\text{Arithmetic sum of EMF}}$$

$$= \frac{E_R}{6E_c}$$

For discrete number of slots

$$K_d = \frac{2 \sin \frac{\pi}{2m}}{\pi \sin \frac{\pi}{m}}$$

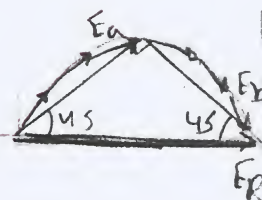
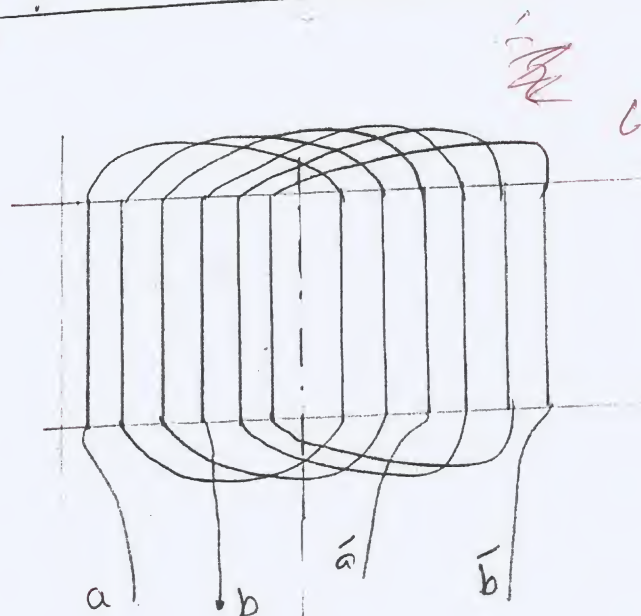


For large number of slots

$$K_d = \frac{E_R}{(\frac{\pi}{2} E_R)}$$

$$K_d = \frac{2}{\pi}$$

$$K_d = \frac{E_R}{\frac{\pi E_R}{2}}$$



2) Two phase machine

$$E_a = E_R \cos 45^\circ = \frac{E_R}{\sqrt{2}}$$

$$K_d = \frac{E_a}{3E_c} = \frac{E_a}{(\frac{\pi}{2} E_R) \times \frac{1}{\sqrt{2}}}$$

$$= \frac{E_R / \sqrt{2}}{(\frac{\pi}{2} E_R) \times \frac{1}{\sqrt{2}}} = \sqrt{2} \left(\frac{2}{\pi} \right)$$

$$K_{d2\phi} = \sqrt{2} K_{d1\phi}$$

∴ EMF in 2-phase increased by 42% from that in single phase.

3) Three-phase machine

$$E_a = \frac{E_R}{2}$$

$$\begin{aligned} K_d &= \frac{E_a}{2 E_c} \\ &= \frac{E_a}{\left(\frac{\pi}{2} E_R\right) \times 1.13} \\ &= \frac{E_R/2}{\left(\frac{\pi}{2} E_R\right) \times 1.13} \\ &= \frac{3}{2} \left(\frac{2}{\pi}\right) \end{aligned}$$

$$K_{d3\phi} = 1.5 K_{d1\phi}$$

So emf increased by 50% from single phase

Why we prefer to use 3-phase system?

For same current rating

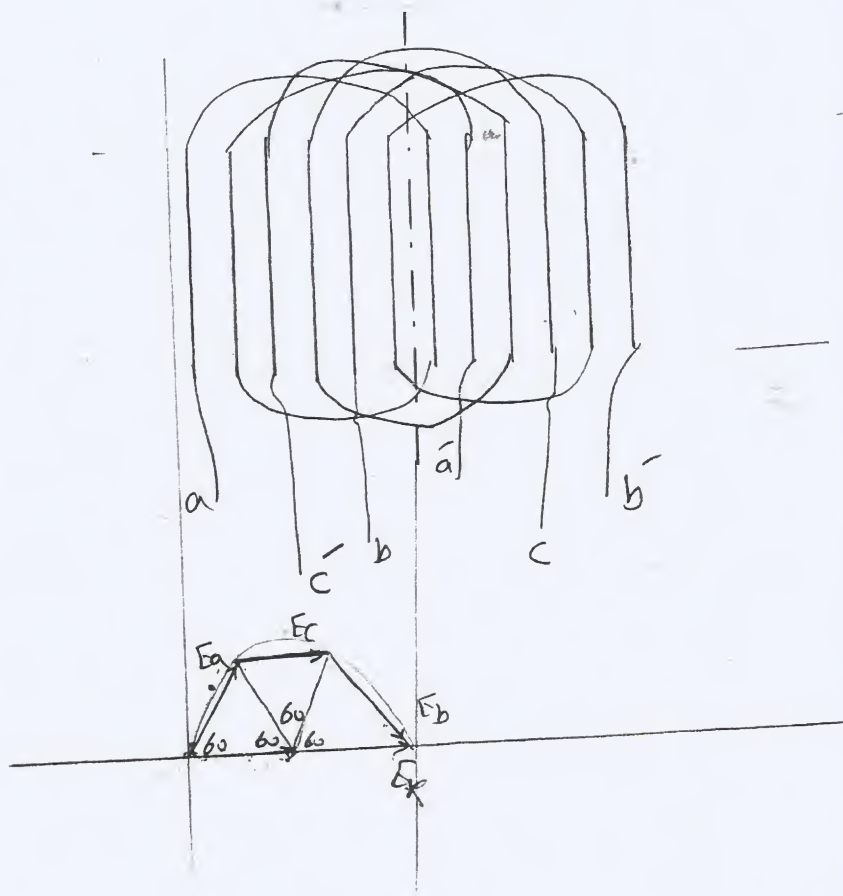
$$P_{1\phi} = E_R I \cos \theta$$

$$P_{2\phi} = 2 E_a I \cos \theta$$

$$= 2 \frac{E_R}{\sqrt{2}} I \cos \theta = \sqrt{2} P_{1\phi}$$

$$P_{3\phi} = 3 E_a I \cos \theta = 3 \frac{E_R}{2} I \cos \theta$$

$$P_{3\phi} = 1.5 P_{1\phi}$$



Assume infinitely number of phases

$$P_{\infty\phi} = (e_1 + e_2 + \dots + e_{\infty}) I \cos \theta$$
$$= \frac{\pi}{2} E_R I \cos \theta$$

$$P_{\infty\phi} = \frac{\pi}{2} P_{1\phi}$$

$$P_{\infty\phi} = 1.57 P_{1\phi}$$

Small increase in Power with large cost [Large number of conductor]

For discrete number of slots

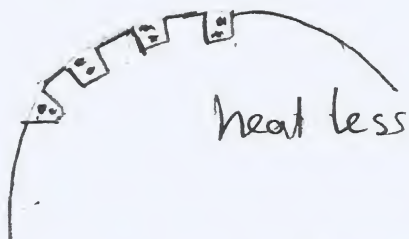
$$K_d = \frac{\sin(9\alpha_s/2)}{9 \sin(\alpha_s/2)} \checkmark$$

α_s = slot angle

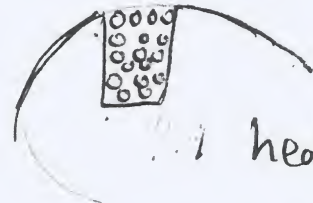
9 = number of slot/pole/phase

Advantages of using distributed conductor

1

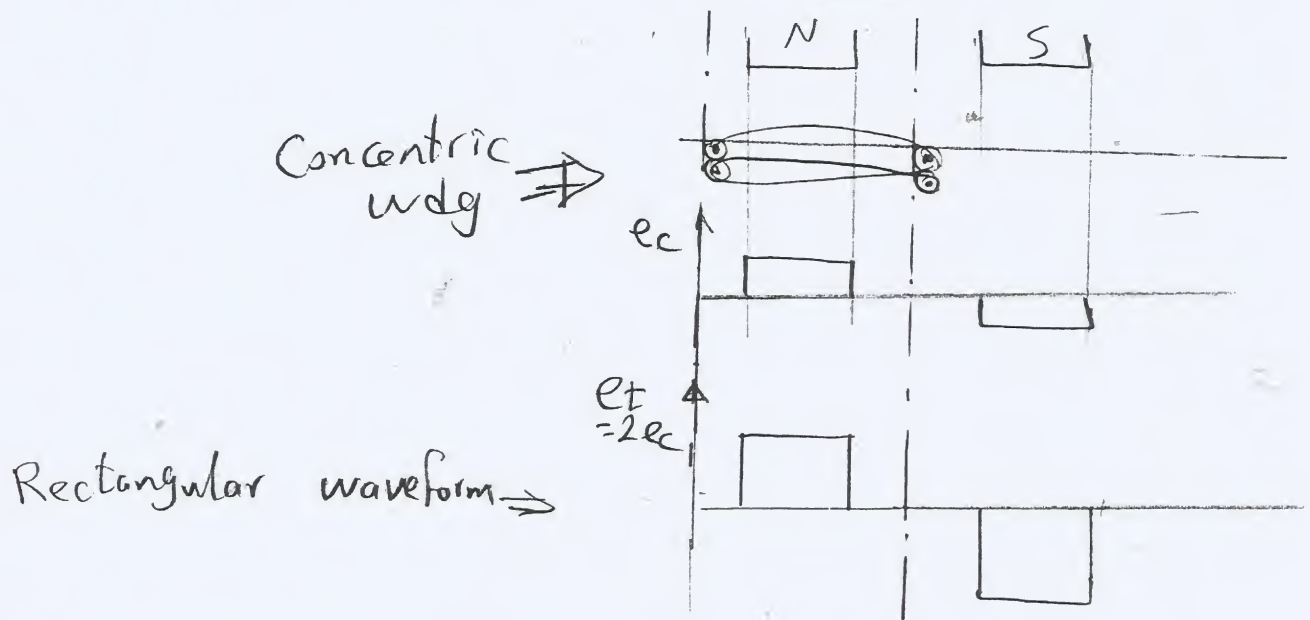


distributed conductor over more than one slot will reduce the temperature \Rightarrow better cooling

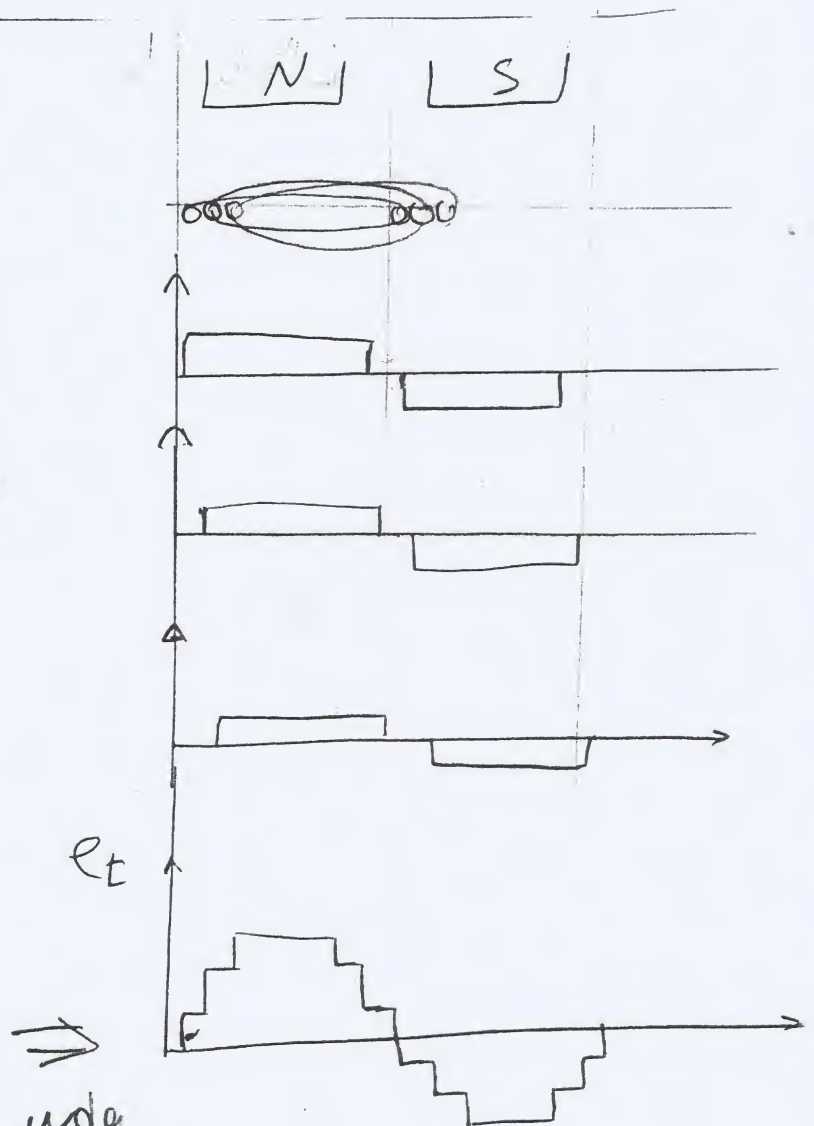


the temperature rise of the conductor at the slot center [hot spot point] bad cooling

2] The waveform Improved [become near to Sinusoidal]



If wdg is distributed

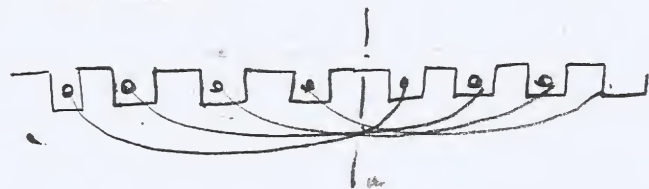


\Rightarrow disadvantage of Distributed wdg
reduce total emf by $k_d < 1$

Single layer & double layer wdg

• Single layer

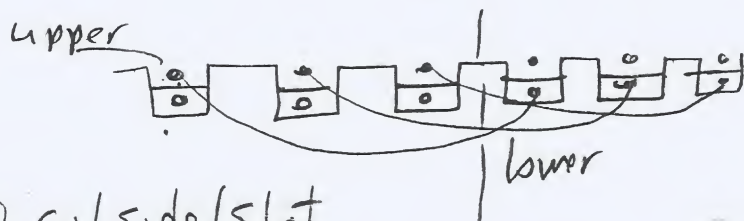
1 coil side/slot



• double layer

used in chording

2 coil side/slot



Chording wdg

τ_c = coil pitch

τ_p = pole pitch

$\tau_c = \tau_p \Rightarrow$ Full pitch

β = chording angle

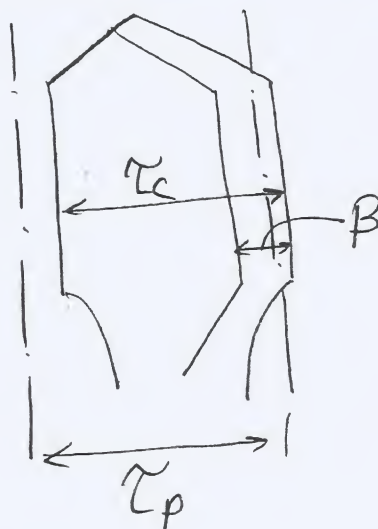
$K_p = \cos(\beta/2)$

For n harmonic order

$K_{pn} = \cos(n\beta/2)$

In chording

$$\tau_c \neq \tau_p$$



Advantage of Chording

1) the waveform of the emf is improved where chording will cancel certain order of harmonic,

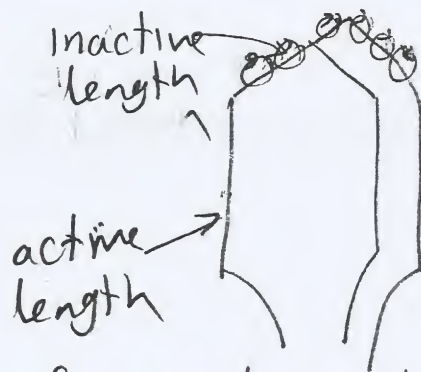
$$K_{p5} = \cos(5\beta/2) \Rightarrow K_{p5} = 0 \text{ when } \frac{5\beta}{2} = 90^\circ$$

$$\beta = 36^\circ$$

to cancel 5th order \Rightarrow must chording by 36°

2) reduce the amount of used copper so that reducing copper resistance, reduce copper loss increase efficiency

3) reduce leakage reactance [reduce inactive length]



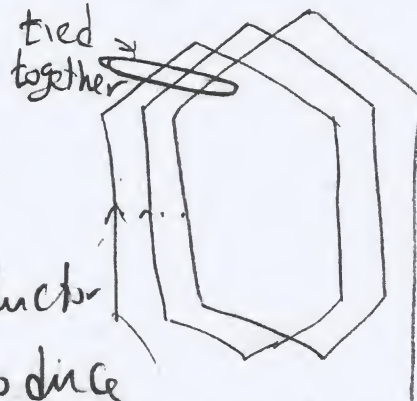
4) the mechanical strength of chording coil is better than unchorded coil

disadvantage of chording wdg

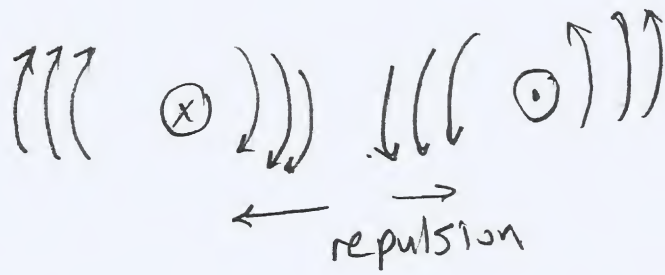
- reduce total induced emf by $k_F < 1$

why transformer wdg must be tied from outside

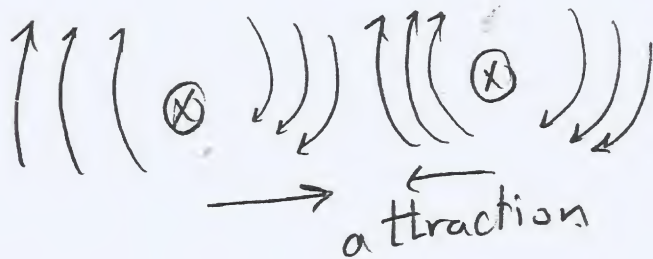
Why we must fix the inactive length together.



When current pass on the conductor it produce flux, which produce a force may be attraction or repulsion [depend on current direction]



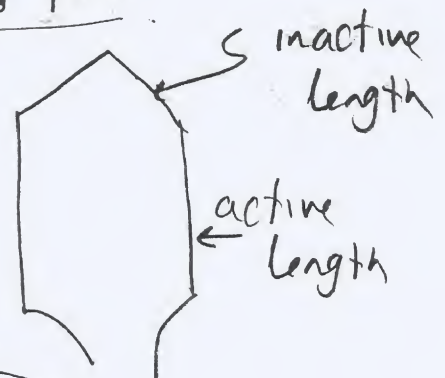
لله من رايه الملفات
باسم من اى، ع



* In transformer primary & secondary current in opposite direction, so when short circuit occur in transformer large repulsion force produce so it must tied the coils together.

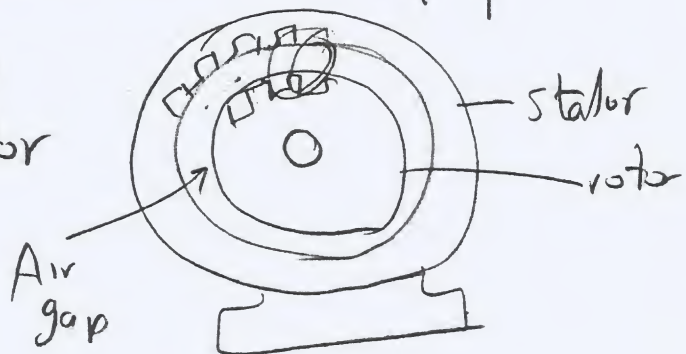
What is the reasons of presented leakage flux

1] inactive length



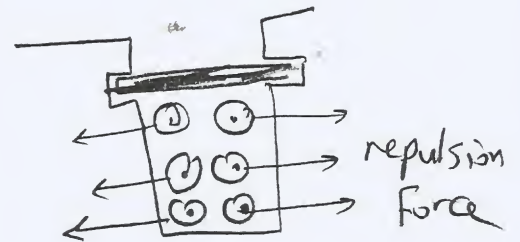
2] Air gap in generator & motor

not all flux produce by stator linked with rotor but there is a leakage flux in air gap



Why in large scale machine must used wedge from nonmagnetic material?

to prevent conduct to go out from slot, due to present of magnetic field, which produce a force.

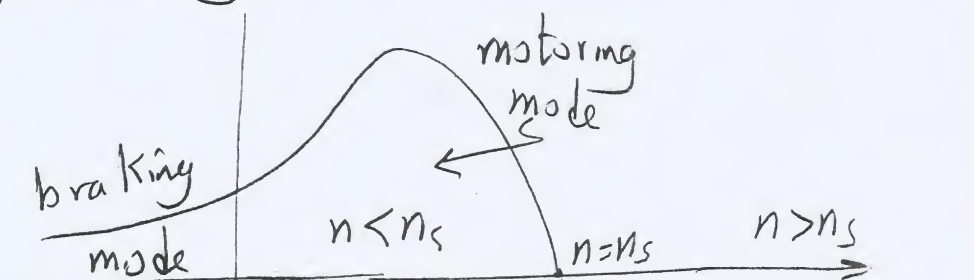


What is the meaning of transformer Power Factor?

transformer hasn't meaning of P-F where it transfer power from primary circuit to Secondary circuit $V_1 I_1 = V_2 I_2$

Draw T-N Chs of Induction machine

Show generating & motoring mode



-to operate as a generator it has source of reactive power so it may draw it from network or use shunt Capacitor

